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(54) **Electric field fingerprint sensor apparatus and related methods**

(57) A fingerprint sensor includes an array of electric field sensing electrodes, a dielectric layer on the sensing electrodes with the dielectric layer for receiving a finger adjacent thereto, a driver for applying an electric field drive signal to the sensing electrodes and adjacent portions of the finger so that the sensing electrodes produce a fingerprint image output signal, the driver provides a coherent drive signal for the array. A respective shield electrode is associated with each of the electric field sensing electrodes for shielding each electric field sensing electrode from adjacent sensing electrodes. Each shield electrode is actively driven for further shielding. The fingerprint sensor includes a synchronous demodulator and contrast enhancer for more accurate output image signals.

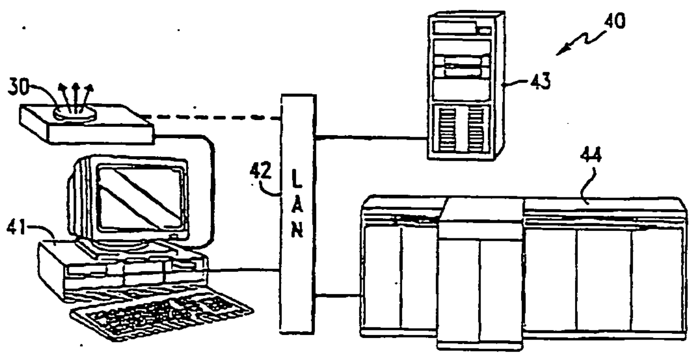

FIG. 2

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Description

The present invention relates to the field of personal identification and verification, and, in particularly, to the field of fingerprint sensing and processing.

Fingerprint sensing and matching is a reliable and widely used technique for personal identification or verification. In particular, a common approach to fingerprint identification involves scanning a sample fingerprint or an image thereof and storing the image and/or unique characteristics of the fingerprint image. The characteristics of a sample fingerprint may be compared to information for reference fingerprints already in storage to determine proper identification of a person, for verification purposes.

A typical electronic fingerprint sensor is based upon illuminating the finger surface using visible light, infrared light, or ultrasonic radiation. The reflected energy is captured with some form of camera, for example, and the resulting image is framed, digitized and stored as a static digital image. The specification of U.S. Patent No. 4,210,899 discloses an optical scanning fingerprint reader cooperating with a central processing station for a secure access application, such as admitting a person to a location or providing access to a computer terminal. The specification of U.S. Patent No. 4,525,859 discloses a video camera for capturing a fingerprint image and uses the minutiae of the fingerprints, that is, the branches and endings of the fingerprint ridges, to determine a match with a database of reference fingerprints.

Unfortunately, optical sensing may be affected by stained fingers or an optical sensor may be deceived by presentation of a photograph or printed image of a fingerprint rather than a true live fingerprint. Accordingly, an optical fingerprint sensor may be unreliable in service in addition to being bulky and relatively expensive due to optics and moving parts.

In the event of a failure to form an acceptable image of a fingerprint, the specification of U.S. Patent No. 4,947,443 discloses a series of indicator lights which give the user a simple go or no-go indication of the acceptability of the fingerprint scanning.

The specification of U.S. Patent No. 4,353,056 discloses another approach to sensing a live fingerprint.

The specification of U.S. Patent No. 5,325,442 discloses a fingerprint sensor including a plurality of sensing electrodes. Active addressing of the sensing electrodes is made possible by the provision of a switching device associated with each sensing electrode.

An object in fingerprint sensing and matching for identification and verification are desirable and may prevent unauthorized use of computer workstations, appliances, vehicles, and confidential data.

An object of the present invention is to provide a fingerprint sensor and related methods for accurately sensing a fingerprint, and which sensor is rugged, compact, reliable and relatively inexpensive.

Advantageously, a fingerprint sensor comprising an array of electric field sensing electrodes, a dielectric layer on the electric field sensing electrodes with the dielectric layer for receiving a finger adjacent thereto, and drive means for applying an electric field drive signal to the electric field sensing electrodes and adjacent portions of the finger so that the electric field sensing electrodes produce a fingerprint image output signal. Accordingly, the many shortcomings and disadvantages of prior art optical sensors are thus overcome, as the sensor in accordance with the present invention may be readily made to be rugged, compact, relatively low cost, and accurate.

In one embodiment the drive means preferably comprises coherent drive means for driving the array with a coherent signal. More particularly, the coherent drive means may include a drive electrode adjacent the electric field sensing electrodes, a second dielectric layer between the drive electrode and the electric field sensing electrodes, and a drive circuit for powering the drive electrode to generate the coherent electric field drive signal with a predetermined frequency. The sensor also preferably includes a finger electrode positioned adjacent the dielectric layer for contact with the finger.

Another important embodiment and aspect of the invention includes a respective shield electrode associated with each of the electric field sensing electrodes for shielding each electric field sensing electrode from adjacent sensing electrodes. Each shield electrode may be provided by an electrically conductive layer surrounding a respective sensing electrode with a dielectric layer there between.

The present invention advantageously includes dynamic contrast enhancing means operatively connected to the electric field sensing electrodes and within the integrated circuit of the sensor for dynamically enhancing contrast and uniformity of the fingerprint image output signal.

The dynamic contrast enhancing means may be provided by a capacitor matrix operatively connected to the electric field sensing electrodes, and an alternating current (AC) capacitor matrix drive means for driving the capacitor matrix. In addition, the AC capacitor matrix drive means may be provided, in part, by the synchronous demodulator described above. The dynamic contrast enhancing means may also comprise a resistor array or matrix operatively connected to the electric field sensing electrodes.

The fingerprint sensor may desirably be implemented using semiconductor processing techniques and wherein the upper dielectric layer, upon which the finger is placed, is an upper exposed portion of the semiconductor chip containing the sensing and drive electrodes, as well as associated active electronic circuitry. In particular, an amplifier may be operatively connected to each electric field sensing electrode, and multiplexing means provided for selectively reading each of the electric field sensing electrodes. The sensor may also preferably include package means in one embodiment for enclosing the substrate, the active semiconductor layer,

the electric field sensing electrodes, and the dielectric layer. The package means preferably has an opening therethrough in registry with the dielectric layer.

The present invention includes a fingerprint sensor comprising:

an array of electric field sensing electrodes;
a dielectric layer on said electric field sensing electrodes, said dielectric layer for receiving a finger adjacent thereto; and
conerent drive means for applying a coherent electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger so that said electric field sensing electrodes produce a fingerprint image output signal.

The invention also includes a method for sensing a fingerprint and generating a fingerprint image output signal, the method comprising the steps of:

providing an array of electric field sensing electrodes with a dielectric layer on said electric field sensing electrodes for receiving a finger adjacent thereto; and
applying a coherent electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger so that said electric field sensing electrodes produce a fingerprint image output signal, including the step of shielding said electric field sensing electrodes by positioning a respective shield electrode surrounding each of said electric field sensing electrodes to shield each electric field sensing electrode from adjacent electric field sensing electrodes.

Conveniently, the fingerprint sensor may interface with the computer processor so that the electronics associated with the sensor may be simplified. Thus, the computer processor preferably comprises access control means for permitting operation of the computer workstation only upon determining a match between a fingerprint sensed by the protectively mounted fingerprint sensor and an authorized reference fingerprint. The fingerprint sensor may be the electric field fingerprint sensor described herein or other sensors may be used.

The invention will now be described, by way of example, with reference to the accompanying drawings in which:

FIG. 1 is a schematic diagram of the fingerprint sensor in combination with a notebook computer;
FIG. 2 is a schematic diagram of the fingerprint sensor in combination with a computer workstation and associated information processing computer and local area network (LAN);
FIG. 3 is a schematic perspective view of an embodiment of a fingerprint sensor in;
FIG. 4 is a schematic plan view of a portion of the sensor and an overlying fingerprint pattern with a portion thereof greatly enlarged for clarity of illustration;
FIG. 5 is a greatly enlarged plan view of a portion of the fingerprint sensor with the upper dielectric layer removed;
FIG. 6 is a schematic perspective view of a portion of the fingerprint sensor;
FIG. 7 is a schematic fragmentary view of a portion of the fingerprint sensor;
FIG. 8 is a schematic side view, partially in section, illustrating the electric fields;
FIG. 9 is a schematic circuit diagram of a portion of the fingerprint sensor;
FIG. 10 is an enlarged schematic side view, partially in section, further illustrating the electric fields;
FIG. 11 is a schematic block diagram of the fingerprint sensor and associated circuitry in one embodiment;
FIG. 12 is a schematic block diagram of the fingerprint sensor and associated circuitry in another embodiment;
FIG. 13 is a schematic block diagram of an embodiment of a sensor circuit;
FIG. 14 is a schematic block diagram of another embodiment of a sensor circuit;
FIG. 15 is a schematic block diagram illustrating a plurality of sensor units;
FIG. 16 is a schematic block diagram of an embodiment of a portion of the signal processing for the fingerprint sensor;
FIG. 17 is a schematic block diagram of another embodiment of a portion of the signal processing for the fingerprint sensor;
FIG. 18 is a schematic block diagram of yet another embodiment of signal processing circuitry for the fingerprint sensor;
FIG. 19 is a schematic circuit diagram of yet another embodiment of a portion of the signal processing for the fingerprint sensor;
FIG. 20 is a schematic circuit diagram of yet another embodiment of a portion of the signal processing for the fingerprint sensor illustrating a resistor matrix for dynamic contrast enhancement;
FIG. 21 is a schematic circuit diagram of yet another embodiment of a portion of the signal processing for the fingerprint sensor illustrating a capacitor matrix implementation for dynamic contrast enhancement;
FIG. 22 is a schematic block diagram of an embodiment of the fingerprint sensor package;
FIG. 23 is a schematic diagram of another embodiment of the fingerprint sensor package;
FIG. 24 is a schematic block diagram of another aspect of the sensor for illustrating near real-time positioning feedback of finger placement;
FIG. 25 is a schematic perspective diagram of a computer illustrating near real-time positioning feedback of finger placement;

FIG. 26 is a schematic perspective diagram of a fingerprint sensor including indicators for illustrating near real-time positioning feedback of finger placement.

Referring to FIGS. 1-3, the fingerprint sensor 30 includes a housing or package 51, a dielectric layer 52 exposed on an upper surface of the package which provides a placement surface for the finger, and a plurality of signal conductors 53. A conductive strip or electrode 54 around the periphery of the dielectric layer 52 also provides a contact electrode for the finger as described in greater detail below. The sensor 30 may provide output signals in a range of sophistication levels depending on the level of processing.

The fingerprint sensor 30 is used for personal identification or verification purposes. For example, the sensor 30 may be used to permit access to a computer workstation, such as a notebook computer 35 including a keyboard 36 and associated folding display screen 37 (FIG. 1). In other words, user access to the information and programs of the notebook computer 35 may only be granted if the desired fingerprint is first sensed.

The sensor 30 may be used to grant or deny access to a fixed workstation 41 for a computer information system 40. The system may include a plurality of such workstations 41 linked by a local area network (LAN) 43, which in turn, is linked to a fingerprint identification server 43, and an overall central computer 44.

Referring to FIGS. 4-10, the sensor 30 is described in greater detail. The sensor 30 includes a plurality of individual pixels or sensing elements 30a arranged in array pattern as shown perhaps best in FIGS. 4 and 5. These sensing elements are relatively small so as to be capable of sensing the ridges 59 and intervening valleys 60 of a typical fingerprint (FIG. 4). Live fingerprint readings as from the electric field sensor 30 may be more reliable than optical sensing, because the conduction of the skin of a finger in a pattern of ridges and valleys is extremely difficult to simulate. In contrast, an optical sensor may be deceived by a readily prepared photograph or other similar image of a fingerprint.

The sensor 30 includes a substrate 65, and one or more active semiconductive layers 66 thereon. A ground plane electrode layer 68 is above the active layer 66 and separated therefrom by an insulating layer 67. A drive electrode layer 71 is positioned over another dielectric layer 70 and is connected to an excitation drive amplifier 74. The excitation drive signal may be typically in the range of about 1 KHz to 1 MHz and is coherently delivered across all of the array. Accordingly, the drive or excitation electronics are thus relatively uncomplicated and the overall cost of the sensor 30 may be reduced, while the reliability is increased.

Another insulating layer 76 is on the drive electrode layer 71, and an illustratively circularly shaped sensing electrode 78 is on the insulating layer 76. The sensing electrode 78 may be connected to sensing electronics 73 formed in the active layer 66 as schematically illustrated.

An annularly shaped shield electrode 80 surrounds the sensing electrode 78 in spaced relation therefrom. As would be readily appreciated by those skilled in the art the sensing electrode 78 and its surrounding shield electrode 80 may have other shapes, such as hexagonal, for example, to facilitate a close packed arrangement or array of pixels or sensing elements 30a. The shield electrode 80 is an active shield which is driven by a portion of the output of the amplifier circuit 73 to help focus the electric field energy and, moreover, to thereby reduce the need to drive adjacent electrodes. Accordingly, the sensor 30 permits all of the sensing elements to be driven by a coherent drive signal in sharp contrast to prior art sensors which required that each sensing electrode be individually driven.

Referring to FIGS. 8-10, the excitation electrode 71 generates a first electric field to the sensing electrode 78 and a second electric field between the sensing electrode 78 and the surface of the finger 79, over the distances d1 and d2, respectively. In other terms, a first capacitor 83 (FIG. 9) is defined between the excitation electrode 71 and the sensing electrode 78, and a second capacitor 85 is defined between the finger skin 79 and ground. The capacitance of the second capacitor 85 varies depending on whether the sensing electrode 78 is adjacent a ridge or valley. Accordingly, the sensor 30 can be modeled as a capacitive voltage divider. The voltage sensed by the unity gain voltage follower or amplifier 73 will change as the distance d2 changes.

The sensing elements 30a operate at very low currents and at very high impedances. For example, the output signal from each sensing electrode 78 is desirably about 5 to 10 millivolts to reduce the effects of noise and permit further processing of the signals. The approximate diameter of each sensing element 30a, as defined by the outer dimensions of the shield electrode 80, may be about 0.002 to 0.005 inches in diameter. The excitation dielectric layer 76 and surface dielectric layer 54 may desirably have a thickness in the range of about 1 µm. The ground plane electrode 68 shields the active electronic devices from the excitation electrode 71. A relatively thick dielectric layer 67 will reduce the capacitance between these two structures and thereby reduce the current needed to drive the excitation electrode. The various signal feedthrough conductors for the electrodes 78, 80 to the active electronic circuitry may be readily formed as would be understood by those skilled in the art. The illustrated signal polarities may be readily reversed.

The overall contact or sensing surface for the sensor 30 may desirably be about 0.5 by 0.5 inches -- a size which may be readily manufactured and still provide a sufficiently large surface for accurate fingerprint sensing and identification. The sensor 30 in accordance with the invention is also fairly tolerant of dead pixels or sensing elements 30a. A typical sensor 30 includes an array of about 256 by 256 pixels or sensor elements, although other array sizes are also contemplated by the present

invention. The sensor 30 may also be fabricated at one time using primarily conventional semiconductor manufacturing techniques to thereby significantly reduce the manufacturing costs.

FIG. 11 refers to functional partitioning of an apparatus 90 including the fingerprint sensor 30 is described. The fingerprint sensor apparatus 90 may be configured to provide one or more of displacement sensing of the fingerprint, provide an image present trigger, perform analog-to-digital conversion, provide full image capture and image integrity determination, provide contrast enhancement and normalization, and provide image binarization. In the illustrated embodiment, the sensor 30 is connected to a parallel processor and memory array 92, and control processor 93 via the illustrated interface 91. The parallel processor 92 may provide image quality and bad block determinations; provide edge enhancement and smoothing and thinning; generate ridge flow vectors, smooth the vectors and generate ridge flow characteristics as may be desired for fingerprint matching; identify the center of the fingerprint; generate, smooth and clean curves; and provide minutiae identification. The illustrated control processor 93 may provide minutiae registration and matching, minutiae storage, generate authorization codes, and communicate with the host via the illustrated interface 94. The illustrated local non-volatile memory 95 may also be included in the apparatus 90.

A variation of the apparatus 90 of FIG. 11 is illustrated by the apparatus 100 of FIG. 12. This embodiment includes a two chip version of the sensor and processing electronics. The apparatus 100 includes a sensor chip 96 and an authenticator chip 97 connected via a local memory bus interface 99. A scan control processor 98 is also included in the illustrated embodiment of FIG. 12, the remaining functional components are the same as in FIG. 11.

Demodulation and preliminary processing of the detected signals from the sensor 30 are further understood with reference to FIGS. 13 and 14. Both of the illustrated circuits 110, 120 desirably use an alternating current excitation. In addition, the amplitude of the voltage on the sensor is proportional to the displacement of the local ground plane, hence, the signal has to be demodulated before further use. FIG. 13 illustrates a local comparator 112 to allow the control to manage the A/D conversion process in parallel. The processor can present a sequence of a reference voltages to an entire row or column of pixels or sensor elements 30a and monitor the transitions on the Sig0 lines. A successive approximation conversion could be implemented, first stepping large steps, and then stepping in progressively finer steps over a smaller range, as would be readily understood by those skilled in the art. The Sig0 output can be a binary bus connection while the SigA output is a demodulated analog signal that can be used as part of analog reference voltage generating circuit.

The circuit 120 illustrated in FIG. 14 has storage to do localized contrast enhancement for all sensor units or pixels simultaneously. The computation can use the analog comparator 112 for a decision element. The binarized output image can be shifted out of the binary shift registers provided by the illustrated latches 113. Alternately, the output image could by read out as with conventional memory array addressing as would be readily understood by those skilled in the art. Since the circuit 120 has its own local memory, it does not need a separate set of buffers to store the pixel data.

Variations in skin conductivity and contamination may cause phase shift of the electric field signal. Accordingly, the processing electronic circuits 110, 120 of FIGS. 13 and 14 preferably include a synchronous demodulator or detector 111 so that the overall circuit has less sensitivity to any such variations in conductivity.

Interconnections of the sensor units or pixels 30a in a portion of an array are schematically illustrated in FIG. 15. Column data transfer lines 121, row data transfer lines 122, and comparator reference lines 123 are shown connected to the array of sensor units 30a. The interconnections may be desirably made in an 8-by-8 block of sensor units.

The circuit 130 of FIG. 16 includes a charge coupled device (CCD) shift register 131 which, in turn, includes a plurality of individual shift registers 135. The shift registers 131 function as a tapped delay line to facilitate image signal processing. The registers 135 feed respective A/D converters 132 operated under control of the illustrated block processor 134. The sensing amplifier outputs are connected to the CCD analog shift registers 135, with one shift register per row of pixels. A row of data is then shifted out of the register either to an A/D converter 132 which serves as the active conversion device. Each pixel is converted to an 8 bit digital word as it arrives at the converter. The conversion process and the A-to-D reference voltage are under control of block processors, where each block processor may control one or more rows, such as, for example, 16 rows per each processor. A limited degree of dynamic contrast compensation can be achieved using data from the previous pixel conversion to scale the reference voltage; however, significant downstream digital image processing may still be required.

The circuit 140 of FIG. 17 is similar to that of FIG. 16. In FIG. 17, a comparator 141 operates under control of the illustrated block processor 134 to provide the image output signals.

FIG. 18 depicts another aspect of the signal processing configurations. This circuit embodiment 150 is similar to that embodiment illustrated in FIG. 11 and described above. The circuit 150 of FIG. 18 illustratively includes a 16-by-16 array of sensor units or image cells 30b selectively addressed and read by the illustrated row select data input multiplexor 151, column select bus drivers 153, and comparator reference voltage dividers 152. Once an image has been captured from the electric field sensing electrodes and digitized, fingerprint features can be extracted from the image. FIG. 18 illus-

trates a high level view of a sensor connected to a bank of digital signal processors 92. A 128 x 128 pixel array, in this instance, has been partitioned into a 16 x 16 array of image cells 30b, wherein each image cell is formed of an 8 x 8 pixel array.

Each image cell 30b has a single comparator reference line that services the entire cell. When a cell 30b is being scanned, one of the parallel processors manages the reference voltage for that cell 30b and records the digitized signals for all of the sensors in that cell. During the process of scanning the sensors in the cell 30b, the processor can simultaneously correlate the data from the cell to generate a preliminary estimate of the ridge flow direction in that cell. In the illustrated embodiment, a control processor 93 manages the sensor signal scanning and digitization, and supervises a bank of parallel processors 92 that perform feature extraction and matching functions.

Turning to FIG. 19, a 4 x 4 processor matrix circuit 180, such as might be used for a pipeline style implementation of the fingerprint minutiae processing, is illustrated. The circuit 180 includes an array of processors 184, a sensor array input/output portion 181, a non-volatile memory interface 182, and the illustrated multiprocessor array clock and control unit 182. The illustrated circuit 180 may be used to identify and locate the fingerprint's unique minutiae to determine a match between a sensed fingerprint and one of a plurality of reference fingerprints. The processors 184 may match the minutiae against a set of previously stored reference minutia, to complete the identification process. When a positive identification has been made, for example, the circuit 180 may notify an external processor by sending an appropriately encrypted message over a host processor interface.

There is a general need to ensure sufficient contrast between the ridges and valleys of the fingerprint over the entire area of the fingerprint. The circuit 160 of FIG. 20 schematically illustrates a resistive network or matrix 161 including a plurality of interconnected resistors 162 for providing dynamic contrast enhancement for the array of pixels 30a. The effect of adjacent pixels is used to normalize the output of each pixel and while providing sufficient contrast. The circuit includes a pair of amplifiers 163, 164 for providing the enhanced contrast output signals.

Each pixel's value is determined by comparing the sensor signal to a reference signal that sums the block reference signal with a weighted average of the signals from all of the sensors in the immediate area. The square resistive grid or matrix provides the necessary weighted average to each of the pixel comparators simultaneously. The global block reference line 165 is preferably driven with a staircase waveform while the comparator outputs are monitored for change of state. Each pixel's gray-scale value may be determined by noting which step of the staircase causes that pixel's comparator to change state.

A variation for dynamic contrast enhancement is understood with reference to the circuit 170 of FIG. 21. Dynamic contrast enhancement can also be implemented by an array 172 of capacitors 171 interconnecting the pixel nodes 174. In this embodiment, the array 172 receives an alternating current signal derived from the synchronous demodulator 175 described in greater detail above. The capacitors 171 serve as an AC impedance network distributing and averaging the AC signals in a fashion analogous to the behavior of the resistive network 161 (FIG. 20) for DC signals. In the AC contrast enhancing circuit 170, the lowpass filtering that in other embodiments may be part of the demodulator circuit, is moved to the comparator 177 circuit portion. The capacitor array 172 is readily implemented using conventional semiconductor processing techniques and may offer an advantage of relatively small size as compared to the resistor array implementation described above.

The resistive matrix circuit 160 and capacitor matrix circuit 170 may provide weighting for image contrast enhancement. An alternative is to conduct such enhancement via downstream software which may take a relatively long time to fully process. Accordingly, the resistor matrix and capacitor matrix arrangement may provide greater overall processing speed. In addition, such preliminary processing at the sensor 30 may allow relaxation of A/D conversion from an 8 bit AD converter to a 1 bit converter in some embodiments, while still providing high speed and at a relatively low cost. For example, processing of the fingerprint image and determination of a match may desirably take only several seconds for certain applications to avoid user frustration.

Referring to FIG. 22, the sensor 30 may be contained within a secure sensor package 190. The sensor 30 is desirably mounted to prevent flexing or shifting which may stress the chip or its electrical connections. More particularly, the overall package may include a tamper resistant housing 191 as would be readily understood by those skilled in the art. For example, the housing 191 may be formed of a hard plastic material or metal that is strong and resistant to cutting, abrading or sawing. Alternately, the housing 191 may be a material which crumbles and destroys its internal circuit components if cutting, dissolution, or other forms of entry are attempted.

The sensor package 190 also includes the illustrated substrate 195, processor 192, destructible memory 195, and encrypted output circuit 194. More particularly, the encrypted output circuit 194 provides an output signal that can only be decrypted by the intended downstream device. Such encryption techniques will be readily understood by those skilled in the art and may include the use of various keys, passwords, codes, etc. The specifications of U.S. Patent Nos. 4,140,272; 5,337,357; 4,993,068 and 5,436,972 each disclose various approaches to encryption.

The output of the sensor package 190 may be communicated to associated downstream decryption equipment via electrically conductive leads or pins, or may be

inductively or optically coupled to associated equipment. Electrical or other types of protection may be provided on the encrypted output portion to ensure that data, such as a database of fingerprints stored on the memory 193, is not readily readable by external connections and/or signal manipulations.

The sensor 30 and processor 192 may be configured to provide any of a range of integral sensor processing features. For example, the encrypted output may be a raw image, a processed image, fingerprint minutiae data, a yes/no match indication, or personal identification and digital signature keys.

The illustrated sensor package 190 also includes a bead 196 of sealing material at the interface between the upper dielectric layer 52 of the sensor 30 and the adjacent portions of the housing 191. Other sealing arrangements are also contemplated by the present invention, for desirably providing a fluid tight seal at the interface between the exposed upper dielectric layer and the adjacent housing portions. In addition, a cleaning liquid may be used to routinely clean the window and reduce the contamination thereof. Since various alcohols, such as isopropyl alcohol are likely to be used as cleaning solutions, the housing 191 and sealing bead 196 are desirably resistant to such chemicals.

Turning to FIG. 23 another sensor package 220 is illustrated, and the problems and solutions with respect to an integrated circuit package are discussed. A fingerprint sensor integrated circuit presents a special packaging difficulty since it has to be touched by the finger being scanned. The main contaminants of concern are sodium and the other alkaline metals. These contaminants may cause mobile ions in the SiO_2 layers that are typically used to passivate the integrated circuit. The resulting oxide charge degrades device characteristics especially in MOS technology.

One conventional approach to controlling mobile ionic contamination uses hermetic packaging with a phosphorus-doped passivation layer over the integrated circuit. The phosphorus doping reduces contaminant mobility by trapping mechanisms. Plastic packaging has now become more widespread, and a silicon nitride passivation layer may be used with the plastic packaging. Silicon nitride may greatly reduce the permeability to contaminants to permit direct contact between the finger of the user and the integrated circuit. Accordingly, silicon nitride may preferably be used as a passivation layer of the fingerprint sensor.

A fingerprint sensor as in the present invention also raises several unique packaging requirements including: the package needs to be open to enable finger-to-sensor die contact; the package should be physically strong in order to withstand rough use; the package and die should be able to withstand repeated cleaning with detergent and/or disinfectant solutions, and including scrubbing; the die should be able to withstand contact with a wide variety of organic and inorganic contaminants, and should be able to withstand abrasion; and finally the package should be relatively inexpensive.

The illustrated package 220 of FIG. 23 addresses these packaging issues. The package 220 includes an integrated circuit die 221 mounted on a metal paddle 222 that is connected to the leadframe 223 during injection molding of the surrounding plastic material 191 of the package. Connections are made by bond wires 227 and the lead frame 223 to the outwardly extending leads 228 as would be readily understood by those skilled in the art. The upper surface of the plastic housing 191 includes an integrally molded opening 52 which permits contact to the die 221. The adhesion between the plastic molding compound and the adjacent upper surface portions of the die creates a seal in this illustrated embodiment. Accordingly, no separate sealing compound or manufacturing step may be needed.

The integrated circuit die 221 may also include a passivation layer 224 of silicon nitride for reasons highlighted above. In addition, as shown in the illustrated sensor package 220, the die 221 may be provided with a second protective coating 225. Each of the coatings 224, 225 are desirably relatively thin, such as on the order of about a micrometer, in order to retain sensor sensitivity. The outer coating 225 may be an organic material, such as polyimide or PTFE (Teflon™) which yields advantages in wear resistance and physical protection. Inorganic coatings, such as silicon carbide or amorphous diamond, may also be used for the outer layer 225 and may greatly enhance wear resistance, especially to abrasive particles In addition, the material of the protective die coating 225 is preferably compatible with standard IC pattern definition methods in order to enable bond pad etching, for example.

The bond pads on the integrated circuit die 221 may be provided by aluminum. Another perhaps more preferable approach seals the pads with a gold plug, as may be applied by electroplating. In order to reduce the height created by the looped bond wires 227, the die 221 may be directly flip-chip bonded in another embodiment of the invention, not shown. The sensor package 220 in other embodiments may be manufactured using tape automated bonding techniques.

Returning to FIG. 22, yet another aspect of the sensor package 190 is that the memory 198 and/or other integrated circuit components may be made to destruct or be rendered secure upon breach of the housing 191, for example. A coating 193 of material may be applied to the integrated circuit die(s) that causes destruction of the die if the coating is dissolved away as would be readily understood by those skilled in the art. The memory 193 may also self-destruct or empty its contents upon exposure to light or upon removal of a sustaining electrical current. Those of skill in the art will readily appreciate other approaches to ensuring the integrity of the data and processing capabilities of the sensor package 190. Accordingly, the present invention provides that sensitive data, such as a database of authorized fingerprints, encryption keys, or authorization codes, are not readily stolen from the sensor package 190. In addition, although the sensor package 190 may desira-

bly incorporate the electrical field sensor 30.

The various embodiments of the sensor 30 and its associated processing circuitry may implement any of a number of conventional fingerprint matching algorithms. Fingerprint minutiae, that is, the branches or bifurcations and end points of the fingerprint ridges, are often used to determine a match between a sample print and a reference print database. Such minutiae matching may be readily implemented by the processing circuitry of the present invention as would be readily understood by those skilled in the art. The specifications in U.S. Patent Nos. 3,859,633 and 3,893,080 are directed to fingerprint identification based upon fingerprint minutiae matching. The specification of U.S. Patent No. 4,151,512 describes a fingerprint classification method using extracted ridge contour data. The specification of U.S. Patent No. 4,185,270 discloses a process for encoding and verification also based upon minutiae. The specification of U.S. Patent No. 5,040,224 discloses an approach to preprocessing fingerprints to correctly determine a position of the core of each fingerprint image for later matching by minutiae patterns.

Because of the relatively fast and efficient processing of a fingerprint image provided by above identified sensor 30 and associated circuitry of the invention, the user may be provided with nearly real-time feedback regarding positioning of his finger on a fingerprint sensor, such as the illustrated electric field sensor 30. Accordingly, the user may quickly and accurately reposition his finger, have his identification accurately determined, and promptly move forward with the intended task. In the past only a simple go or no-go indication has been described for a user as in the specification of U.S. Patent No. 4,947,443 and with such an indication most likely taking a relatively long time. Unless such an indication can be given within several seconds, user frustration is likely to rise dramatically with any further passage of time. Moreover, a simple go/no-go indication may only prompt the user to try again without any useful guidance on what may be causing the no-go indication.

The apparatus 200 (FIG. 24) illustratively includes a fingerprint sensor 30 operatively connected to an image processor 201. Along the lines as discussed above, the image processor 201 may include the tapped delay line or other functional center point calculator 202 for determining a center point from the sensed fingerprint as will be readily appreciated by those skilled in the art. The location of the center point relative to a predetermined reference center point may be determined and an indication given the user via a position indicator 203. The image may also be further analyzed, and if the applied finger pressure is too great or too little, such an indication may also be given to the user. Accordingly, potential user frustration may be significantly reduced. A need to clean the sensor may also be effectively communicated to the user if repositioning and/or pressure changes are ineffective, such as after a predetermined number of attempts.

Turning to FIG. 25, a practical implementation of the position feedback sensing and indication is further described as applied in a computer workstation, such as the illustrated notebook computer 35 of the type including a keyboard 36 and display 37.

The fingerprint sensor 30 receives the finger of the user. The processor of the computer in cooperation with the fingerprint sensor 30 generates a display of the fingerprint image 206 along with its center point 205 on an image of a window 207 on the display 37. The display also includes a target center point 208 to assist the user is repositioning his finger for an accurate reading.

In addition to the visual image indication, a further indication may be given by display of the words "move upward" and "move left" along with the illustrated associated directional arrows. An indication may also be given concerning a desired pressure, such as the illustrated words "increase pressure".

Yet another variation of the feedback and pressure indications may be in the form of synthetically generated speech messages issued from a speaker 39 mounted within the housing of the computer. For example, the generated voice messages illustratively include an annunciation to "move finger up and to the left" and "increase finger pressure".

Still another embodiment of finger position feedback sensing and indication is understood with further reference to the apparatus 210 of FIG. 26. In this embodiment, the sensor 30 is used to operate an access controller 211 which, in turn, may operate a door, for example, to permit a properly identified user to enter. Simple visual indications in the form of LEDs 212, 213 for up and down motion, and left and right motion, respectively, may be provided to indicate to the user the proper positioning or repositioning of his finger. The illustrated embodiment also includes a plurality of LEDs 214 for indication of pressure.

A fingerprint sensor includes an array of electric field sensing electrodes, a dielectric layer on the sensing electrodes with the dielectric layer for receiving a finger adjacent thereto, a driver for applying an electric field drive signal to the sensing electrodes and adjacent portions of the finger so that the sensing electrodes produce a fingerprint image output signal, the driver provides a coherent drive signal for the array. A respective shield electrode is associated with each of the electric field sensing electrodes for shielding each electric field sensing electrode from adjacent sensing electrodes. Each shield electrode is actively driven for further shielding. The fingerprint sensor includes a synchronous demodulator and contrast enhancer for more accurate output image signals.

Claims

1. A fingerprint sensor comprising:

    an array of electric field sensing electrodes;
    a dielectric layer on said electric field sensing

electrodes, said dielectric layer for receiving a finger adjacent thereto: and
coherent drive means for applying a coherent electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger so that said electric field sensing electrodes produce a fingerprint image output signal.

2. A fingerprint sensor as claimed in Claim 1 wherein said coherent drive means comprises:

a drive electrode adjacent said electric field sensing electrodes;
a second dielectric layer between said drive electrode and said electric field sensing electrodes;
a drive circuit for powering said drive electrode to generate the coherent electric field drive signal having a predetermined frequency, and a finger electrode positioned adjacent said dielectric layer for contact with the finger.

3. A fingerprint sensor as claimed in Claim 1 or 2 wherein a respective shield electrode associated with each of said electric field sensing electrodes for shielding each electric field sensing electrode from adjacent sensing electrodes, and each shield electrode comprises an electrically conductive layer surrounding a respective electric field sensing electrode with a dielectric layer therebetween, with an active shield driving means for actively driving each of said shield electrodes, preferably said active shield driving means comprising an amplifier operatively connected to each electric field sensing electrode and its associated shield electrode for actively driving the shield electrode with a portion of an output signal from said amplifier.

4. A fingerprint sensor as claimed in any one of Claims 1 to 3 wherein synchronous demodulator means operatively connected to said electric field sensing electrodes for synchronously demodulating signals therefrom, with dynamic contrast enhancing means operatively connected to said electric field sensing electrodes for dynamically enhancing contrast and uniformity of the fingerprint image output signal, in which said dynamic contrast enhancing means comprises

a capacitor matrix operatively connected to said electric field sensing electrodes; and
alternating current capacitor matrix drive means for driving said capacitor matrix.

5. A fingerprint sensor as claimed in any one of Claims 1 to 4 wherein said alternating current capacitor matrix drive means comprises a synchronous demodulator, said dynamic contrast enhancing means comprises a resistor matrix operatively connected to said electric field sensing electrodes, an amplifier operatively connected to each electric field sensing electrode, multiplexing means for selectively reading each of said electric field sensing electrodes, including

a substrate; and
an active semiconductor layer on said substrate comprising a plurality of semiconductor devices operatively connected to said electric field sensing electrodes.

6. A fingerprint sensor as claimed in Claim 5 including package means for enclosing said substrate, said active semiconductor layer, said electric field sensing electrodes, said dielectric layer; in which said package means has an opening therethrough in registry with said dielectric layer.

7. A fingerprint sensor comprising:

an array of electric field sensing electrodes;
a dielectric layer on said electric field sensing electrodes, said dielectric layer for receiving a finger adjacent thereto;
a respective shield electrode associated with each of said electric field sensing electrodes for shielding each electric field sensing electrode from adjacent electric field sensing electrodes; and
drive means for applying an electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger so that said electric field sensing electrodes produce a fingerprint image output signal, with each shield electrode comprising an electrically conductive layer surrounding a respective electric field sensing electrode with a dielectric layer therebetween, including active shield driving means for actively driving each of said shield electrodes, in which said active shield driving means comprises an amplifier operatively connected to each electric field sensing electrode and its associated shield electrode for actively driving the shield electrode with a portion of an output signal from the amplifier.

8. A fingerprint sensor as claimed in Claim 7 wherein said drive means comprises:

a drive electrode adjacent said electric field sensing electrodes;
a second dielectric layer between said drive electrode and said electric field sensing electrodes; and a drive circuit for powering said drive electrode to generate the electric field drive signal having a predetermined frequency, a finger electrode positioned adjacent said die-

lectric layer for contact with the finger, a synchronous demodulator means operatively connected to said electric field sensing electrodes for synchronously demodulating signals therefrom, a dynamic contrast enhancing means operatively connected to said electric field sensing electrodes for dynamically enhancing contrast and uniformity of the fingerprint image output signal, with said dynamic contrast enhancing means comprising:

a capacitor matrix operatively connected to said electric field sensing electrodes;
alternating current capacitor matrix drive means for driving said capacitor matrix, said alternating current capacitor matrix drive means comprises a synchronous demodulator, and said dynamic contrast enhancing means comprises a resistor matrix operatively connected to said electric field sensing electrodes.

9. A fingerprint sensor comprising:

a substrate;
an array of electric field sensing electrodes adjacent said substrate;
a dielectric layer on said electric field sensing electrodes, said dielectric layer for receiving a finger adjacent thereto;
drive means for applying an electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger so that said electric field sensing electrodes produce a fingerprint image output signal; and
contrast enhancing means adjacent said substrate and operatively connected to said electric field sensing electrodes for enhancing contrast of the fingerprint image output signal, said contrast enhancing means comprises dynamic contrast enhancing means for dynamically enhancing contrast and uniformity of the fingerprint image output signal, said dynamic contrast enhancing means comprises:

a capacitor matrix operatively connected to said electric field sensing electrodes; and
alternating current capacitor matrix drive means for driving said capacitor matrix, said alternating current capacitor matrix drive means comprises a synchronous demodulator, said dynamic contrast enhancing means comprises a resistor matrix operatively connected to said electric field sensing electrodes, in which said drive means comprises:

a drive electrode adjacent said electric field sensing electrodes;
a second dielectric layer between said drive electrode and said electric field sensing electrodes; and
a drive circuit for powering said drive electrode to generate the electric field drive signal having a predetermined frequency, and a finger electrode positioned adjacent said dielectric layer for contact with the finger.

10. A fingerprint sensor as claimed in Claim 9 including a respective shield electrode associated with each of said electric field sensing electrodes for shielding each electric field sensing electrode from adjacent sensing electrodes, active shield driving means for actively driving each of said shield electrodes, synchronous demodulator means operatively connected to said electric field sensing electrodes for synchronously demodulating signals therefrom, and package means for enclosing said substrate, said electric field sensing electrodes, said contrast enhancing means and said dielectric layer; and wherein said package means has an opening therethrough in registry with said dielectric layer.

11. A computer workstation comprising:

a housing;
a computer processor positioned within said housing;
a display operatively connected to said computer processor;
a keyboard operatively connected to said computer processor; and
fingerprint sensor means operatively connected to said computer processor and mounted within said housing for protection thereby, said fingerprint sensor means comprising a finger sensing surface exposed through an opening in said housing;
said computer processor comprising access control means for permitting operation of the computer workstation only upon determining a match between a fingerprint sensed by said fingerprint sensor means and an authorized reference fingerprint, in which said fingerprint sensor means comprises an electric field fingerprint sensor, including an array of electric field sensing electrodes,
a dielectric layer on said electric field sensing electrodes, said dielectric layer for receiving a finger adjacent thereto; and
drive means for applying an electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger so that said electric field sensing electrodes produce a fingerprint image output signal.

12. A computer workstation as claimed in Claim 11

wherein said drive means comprises:

a drive electrode adjacent said electric field sensing electrodes;
a second dielectric layer between said drive electrode and said electric field sensing electrodes;
a coherent drive circuit for powering said drive electrode to generate a coherent electric field drive signal having a predetermined frequency, a respective shield electrode associated with each of said electric field sensing electrodes for shielding each electric field sensing electrode from adjacent sensing electrodes, active shield driving means for actively driving each of said shield electrodes, synchronous demodulator means operatively connected to said electric field sensing electrodes for synchronously demodulating signals therefrom, and dynamic contrast enhancing means operatively connected to said electric field sensing electrodes for dynamically enhancing contrast and uniformity of the fingerprint image output signal.

13. A method for sensing a fingerprint and generating a fingerprint image output signal, the method comprising the steps of:

providing an array of electric field sensing electrodes with a dielectric layer on said electric field sensing electrodes for receiving a finger adjacent thereto; and
applying a coherent electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger so that said electric field sensing electrodes produce a fingerprint image output signal, including the step of shielding said electric field sensing electrodes by positioning a respective shield electrode surrounding each of said electric field sensing electrodes to shield each electric field sensing electrode from adjacent electric field sensing electrodes.

14. A method as claimed in Claim 13 including the step of actively driving each of said shield electrodes with a portion of an output signal from an amplifier associated with each electric field sensing electrode, the step of synchronously demodulating signals from said electric field sensing electrodes, and the step of dynamic enhancing contrast and uniformity of the fingerprint image output signal.

15. A method for sensing a fingerprint and generating a fingerprint image output signal, as claimed in Claims 13 and 14 in which the method comprising the steps of:

providing an array of electric field sensing electrodes with a dielectric layer on said electric field sensing electrodes for receiving a finger adjacent thereto;
applying an electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger so that said electric field sensing electrodes produce a fingerprint image output signal; and
shielding said electric field sensing electrodes by positioning a respective shield electrode surrounding each of said electric field sensing electrodes to shield each electric field sensing electrode from adjacent sensing electrodes, and including the step of actively driving each of said shield electrodes with a portion of an output signal from an amplifier associated with each electric field sensing electrode.

16. A method for sensing a fingerprint and generating a fingerprint image output signal, the method comprising the steps of:

providing an array of electric field sensing electrodes with a dielectric layer on said electric field sensing electrodes for receiving a finger adjacent thereto and with a switched capacitor array operatively connected to said electric field sensing electrodes;
applying an electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger so that said electric field sensing electrodes produce a fingerprint image output signal; and
applying an alternating current drive signal to a capacitor matrix operatively connected to said electric field sensing electrodes to thereby enhance contrast and uniformity of the fingerprint image output signal, in which the step of applying an alternating current drive signal to the capacitor matrix comprises applying a synchronously demodulated output of said sensing electrodes to the capacitor matrix.

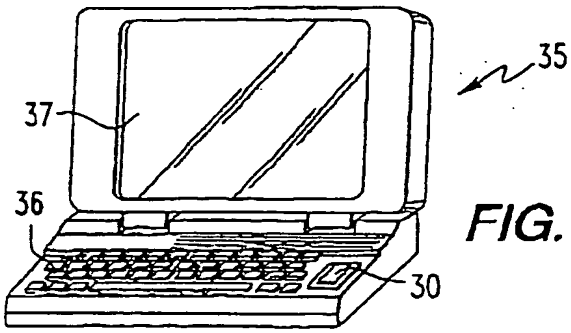


FIG. 1

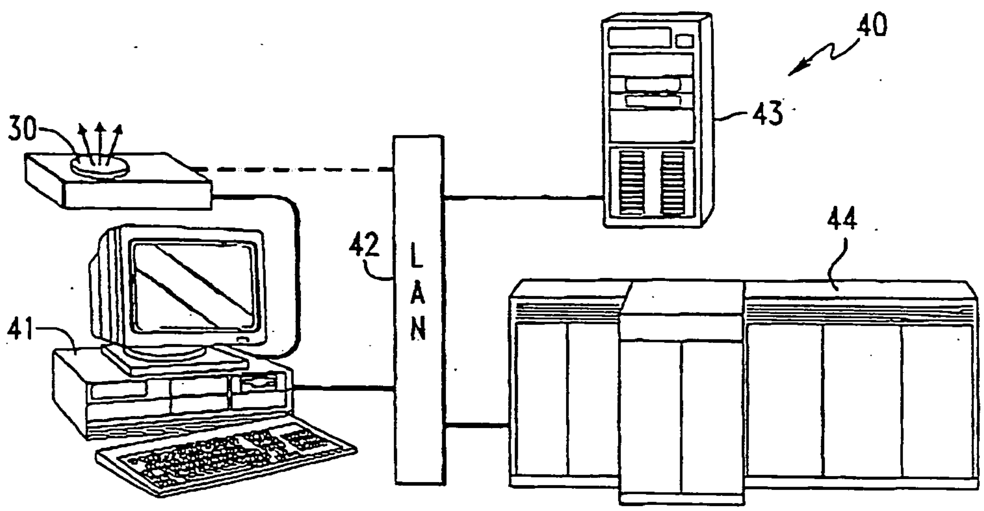


FIG. 2

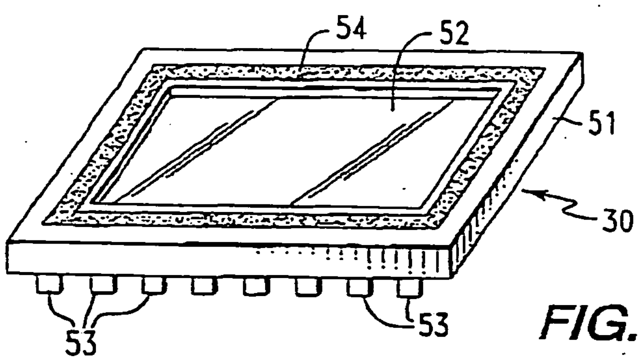


FIG. 3

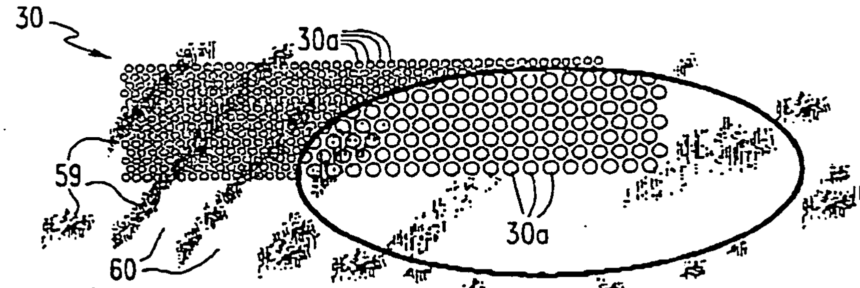


FIG. 4

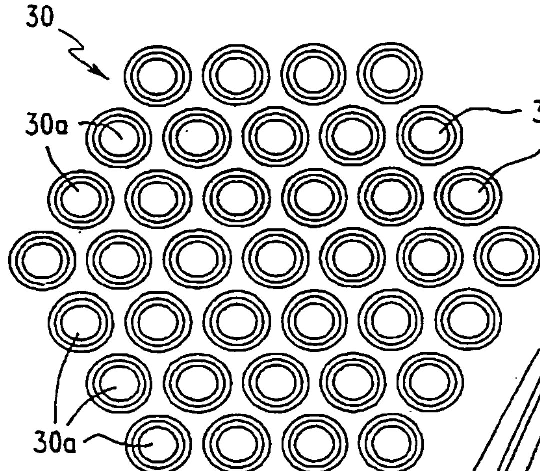


FIG. 5

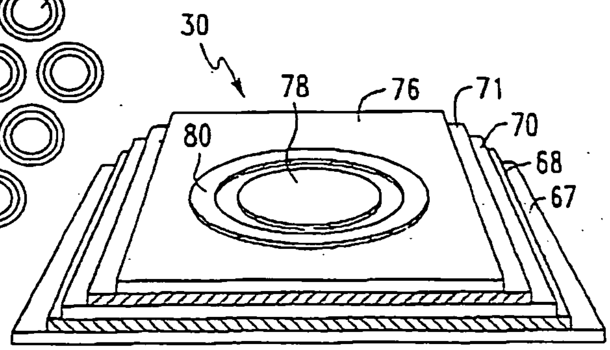


FIG. 6

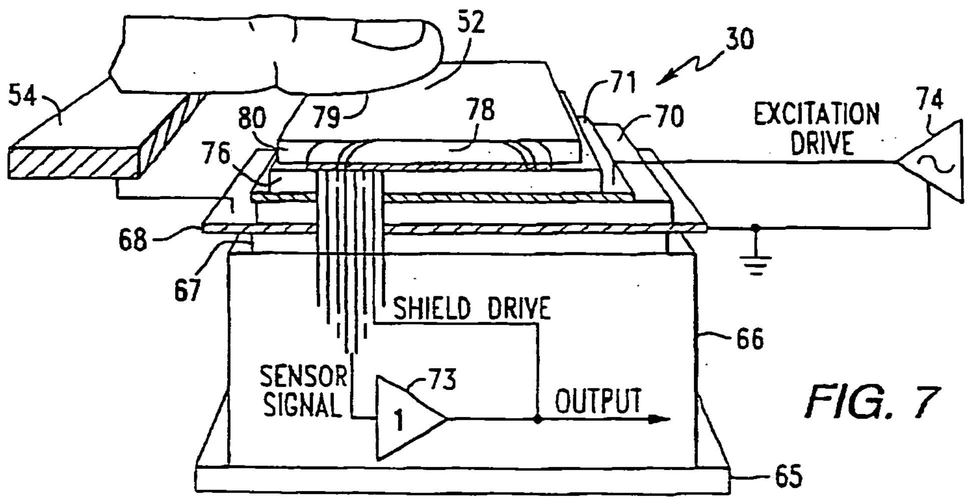


FIG. 7

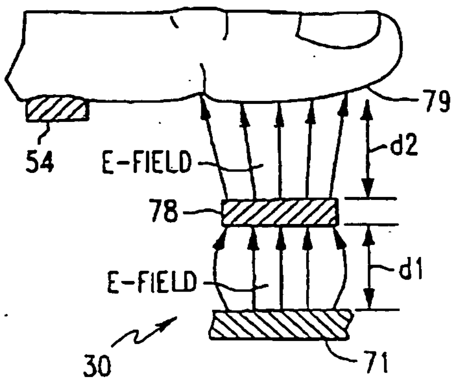


FIG. 8

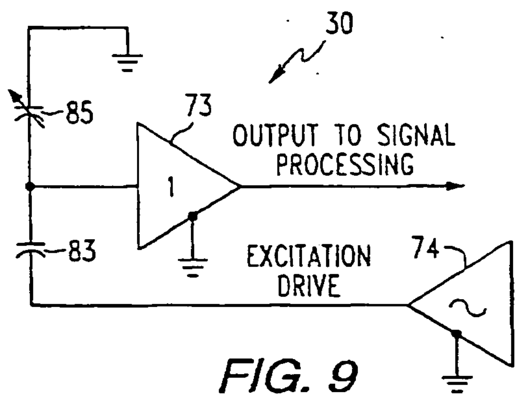


FIG. 9

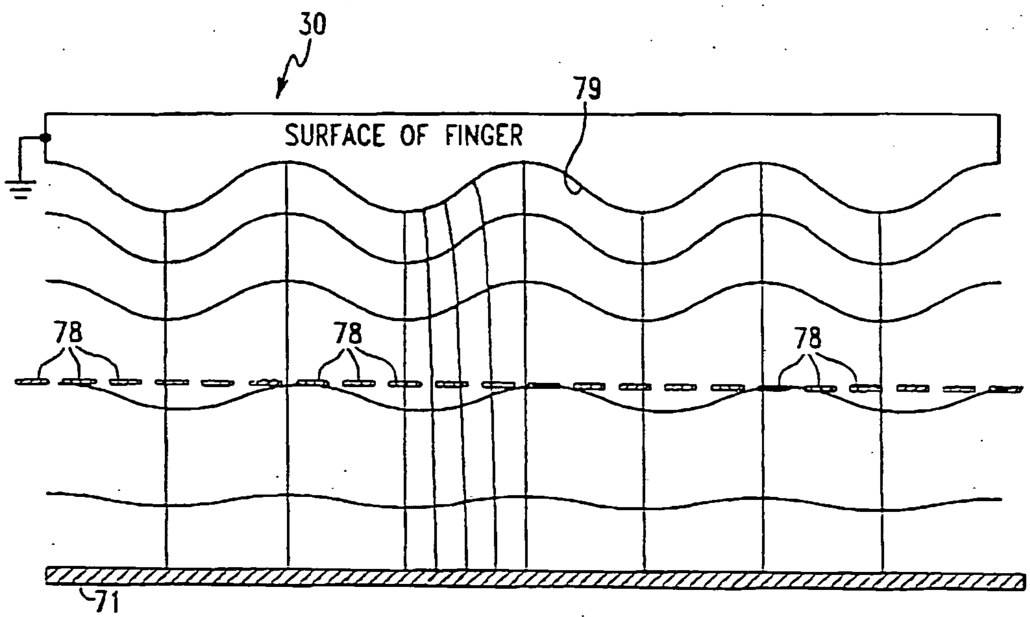


FIG. 10

FIG. 11

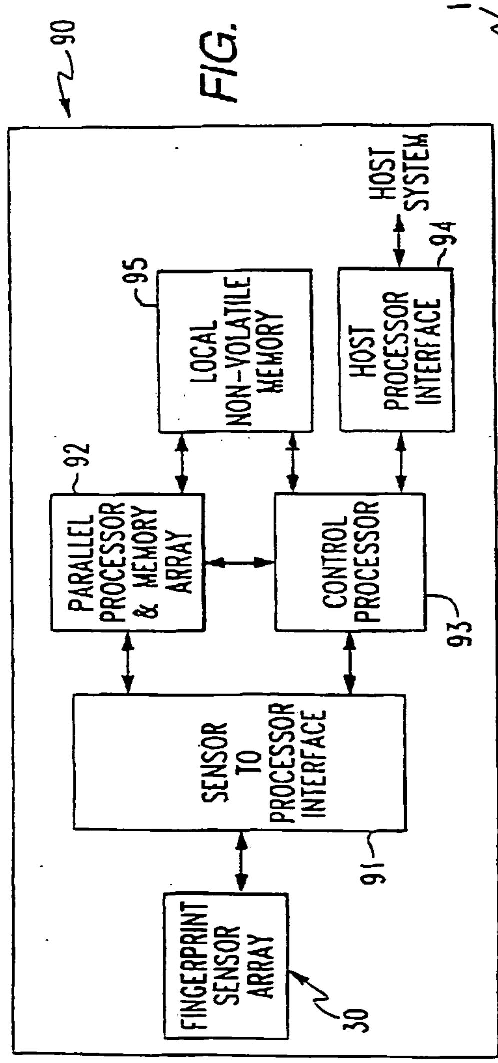
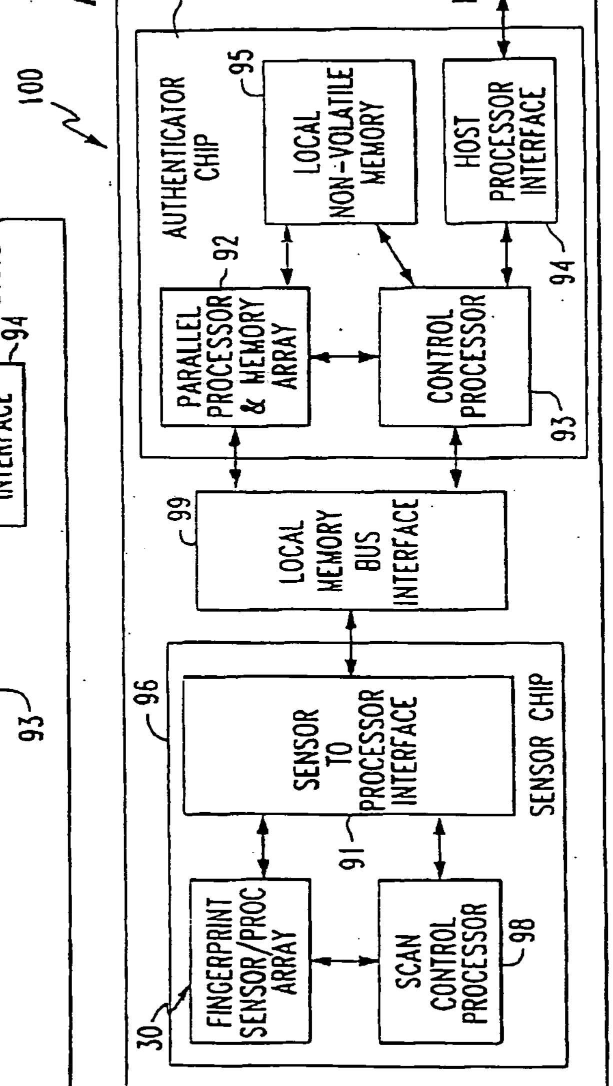

90
FINGERPRINT SENSOR ARRAY
30
SENSOR TO PROCESSOR INTERFACE
91
PARALLEL PROCESSOR & MEMORY ARRAY
92
CONTROL PROCESSOR
93
LOCAL NON-VOLATILE MEMORY
95
HOST PROCESSOR INTERFACE
94
HOST SYSTEM

FIG. 12


100
97
AUTHENTICATOR CHIP
LOCAL NON-VOLATILE MEMORY
95
HOST PROCESSOR INTERFACE
94
HIGH-SPEED SERIAL INTERFACE
PARALLEL PROCESSOR & MEMORY ARRAY
92
CONTROL PROCESSOR
93
LOCAL MEMORY BUS INTERFACE
99
SENSOR TO PROCESSOR INTERFACE
91
96
SENSOR CHIP
FINGERPRINT SENSOR/PROC ARRAY
30
SCAN CONTROL PROCESSOR
98

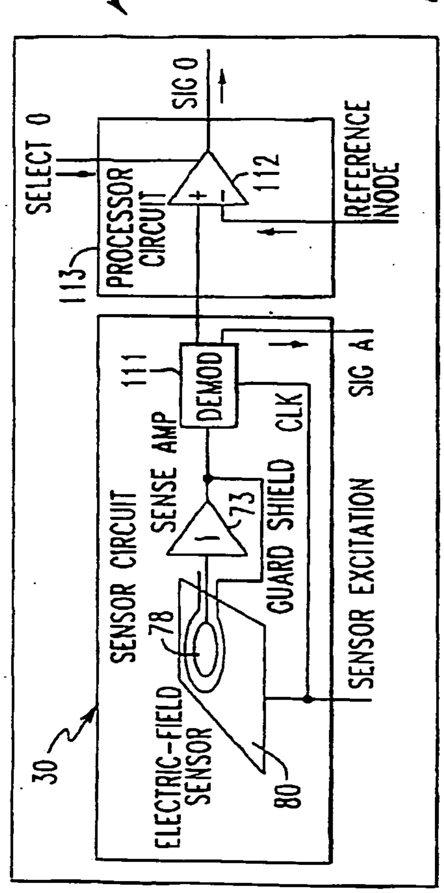

110
SELECT 0
PROCESSOR CIRCUIT
113
112
SIG 0
REFERENCE NODE
SENSOR CIRCUIT
SENSE AMP
111
DEMOD
SIG A
73
78
GUARD SHIELD
CLK
ELECTRIC-FIELD SENSOR
30
80
SENSOR EXCITATION

FIG. 13

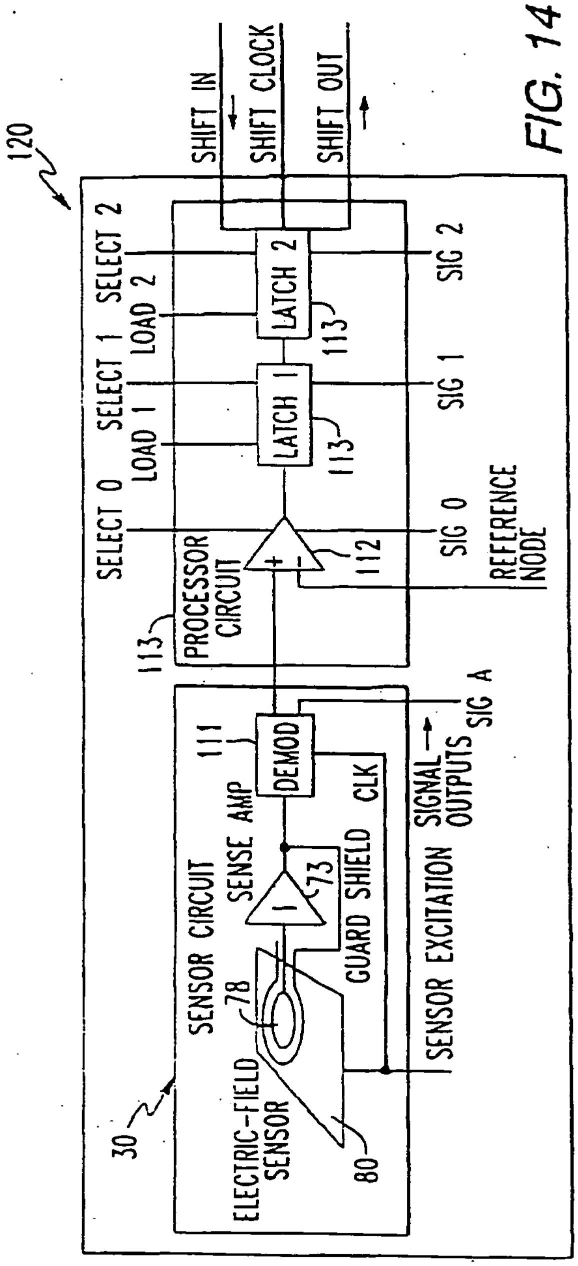

120
SHIFT IN
SHIFT CLOCK
SHIFT OUT
SELECT 0
SELECT 1
SELECT 2
LOAD 1
LOAD 2
LATCH 1
LATCH 2
113
PROCESSOR CIRCUIT
112
SIG 0
SIG 1
SIG 2
REFERENCE NODE
SENSOR CIRCUIT
SENSE AMP
111
DEMOD
CLK
SIG A
SIGNAL OUTPUTS
73
78
GUARD SHIELD
ELECTRIC-FIELD SENSOR
30
80
SENSOR EXCITATION

FIG. 14

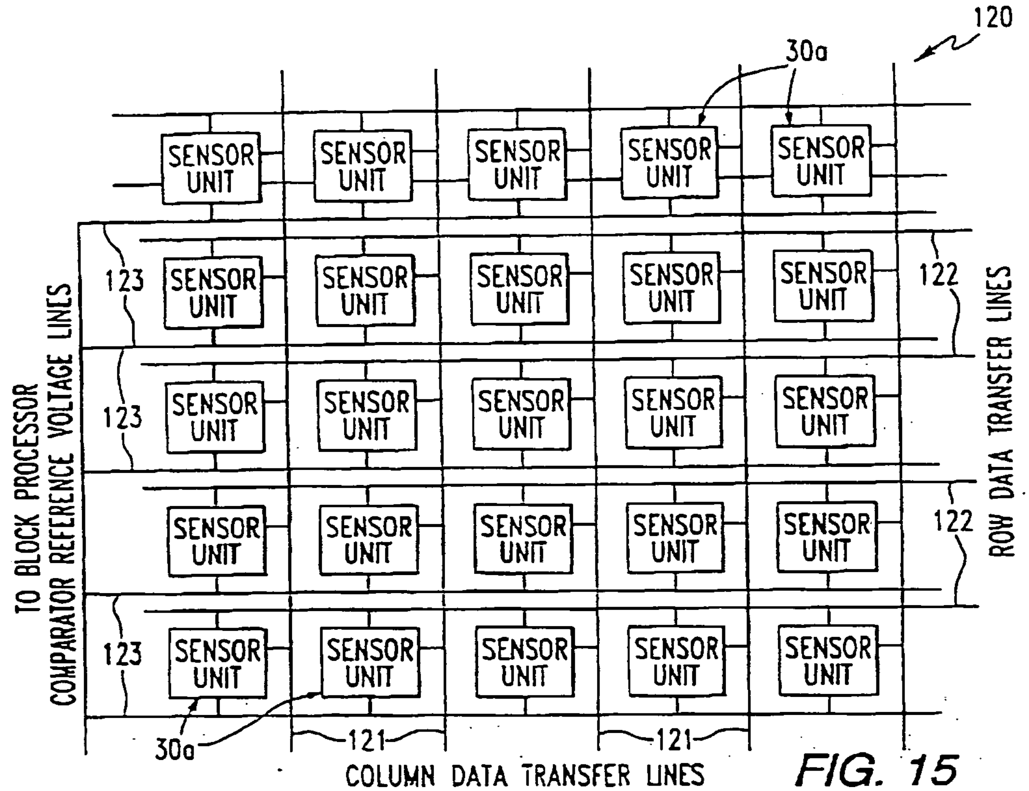

120
30a
SENSOR UNIT
123
122
TO BLOCK PROCESSOR
COMPARATOR REFERENCE VOLTAGE LINES
ROW DATA TRANSFER LINES
30a
121
COLUMN DATA TRANSFER LINES

FIG. 15

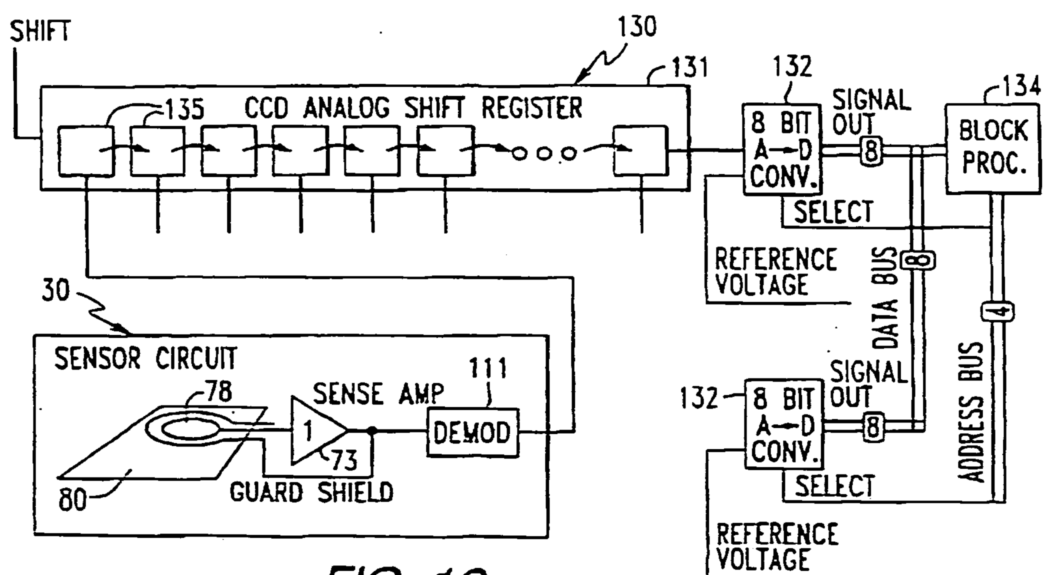

SHIFT
130
131
135
CCD ANALOG SHIFT REGISTER
132
8 BIT A→D CONV.
SIGNAL OUT
8
134
BLOCK PROC.
SELECT
REFERENCE VOLTAGE
DATA BUS
4
ADDRESS BUS
30
SENSOR CIRCUIT
78
SENSE AMP
111
1
DEMOD
73
80
GUARD SHIELD
132
8 BIT A→D CONV.
SIGNAL OUT
SELECT
REFERENCE VOLTAGE

FIG. 16

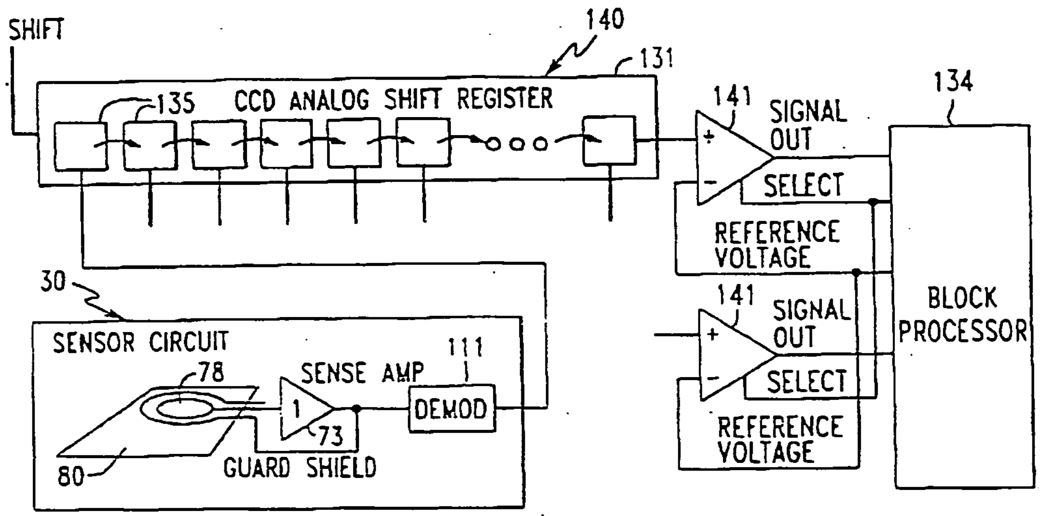

SHIFT
140
131
135
CCD ANALOG SHIFT REGISTER
141
SIGNAL OUT
SELECT
REFERENCE VOLTAGE
134
BLOCK PROCESSOR
30
SENSOR CIRCUIT
78
SENSE AMP
111
DEMOD
73
80
GUARD SHIELD
141
SIGNAL OUT
SELECT
REFERENCE VOLTAGE

FIG. 17

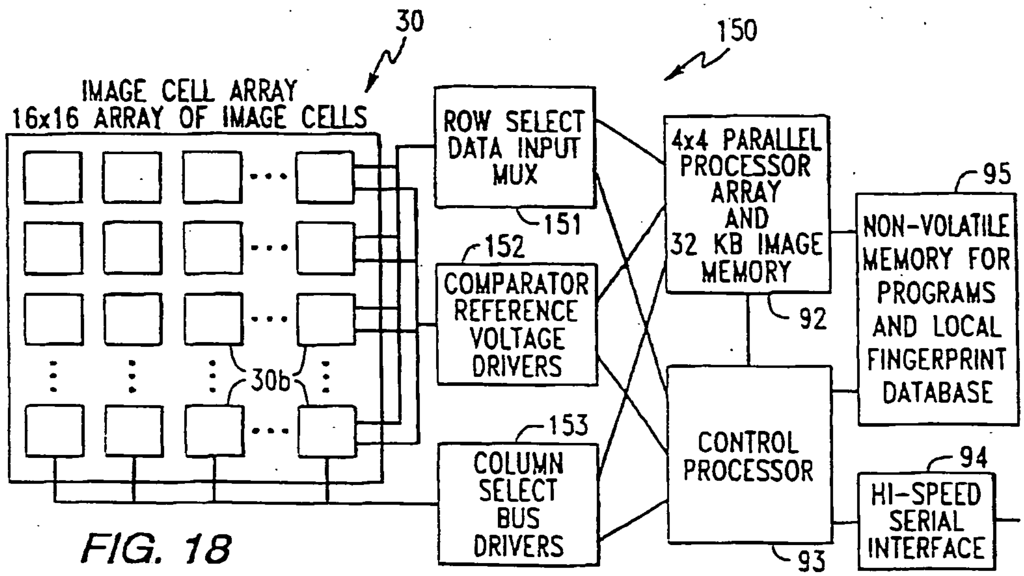

30
IMAGE CELL ARRAY
16x16 ARRAY OF IMAGE CELLS
30b
ROW SELECT DATA INPUT MUX
151
152
COMPARATOR REFERENCE VOLTAGE DRIVERS
153
COLUMN SELECT BUS DRIVERS
150
4x4 PARALLEL PROCESSOR ARRAY AND 32 KB IMAGE MEMORY
92
CONTROL PROCESSOR
93
95
NON-VOLATILE MEMORY FOR PROGRAMS AND LOCAL FINGERPRINT DATABASE
94
HI-SPEED SERIAL INTERFACE

FIG. 18

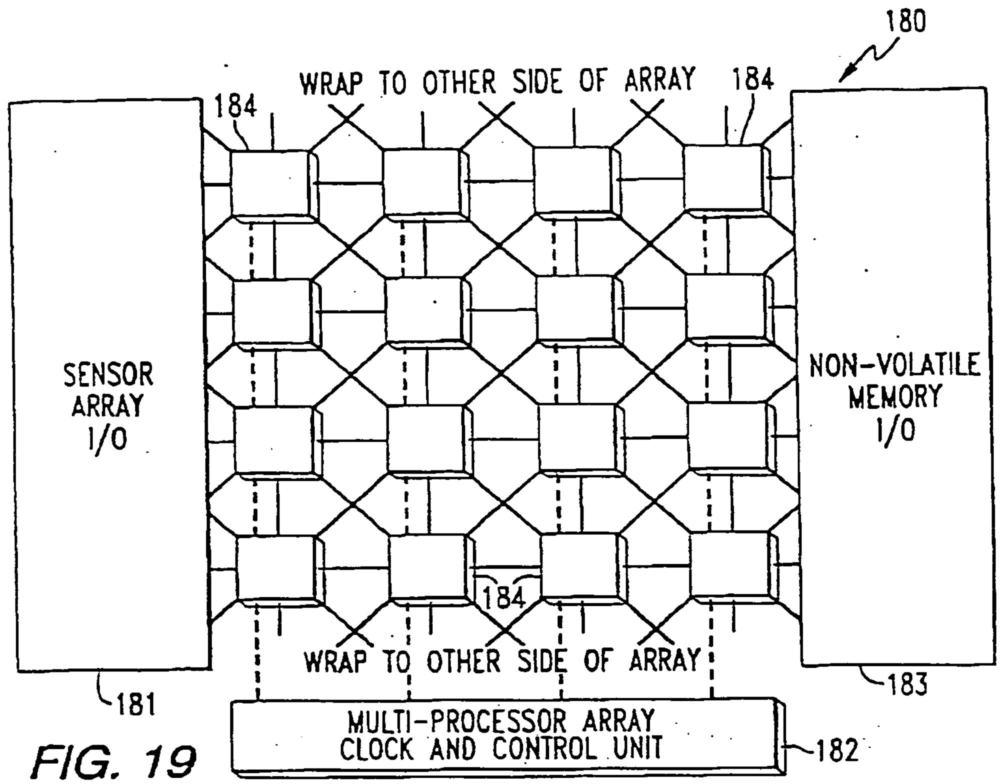

180
WRAP TO OTHER SIDE OF ARRAY
184
184
SENSOR ARRAY I/O
NON-VOLATILE MEMORY I/O
184
WRAP TO OTHER SIDE OF ARRAY
181
183
MULTI-PROCESSOR ARRAY CLOCK AND CONTROL UNIT
182

FIG. 19

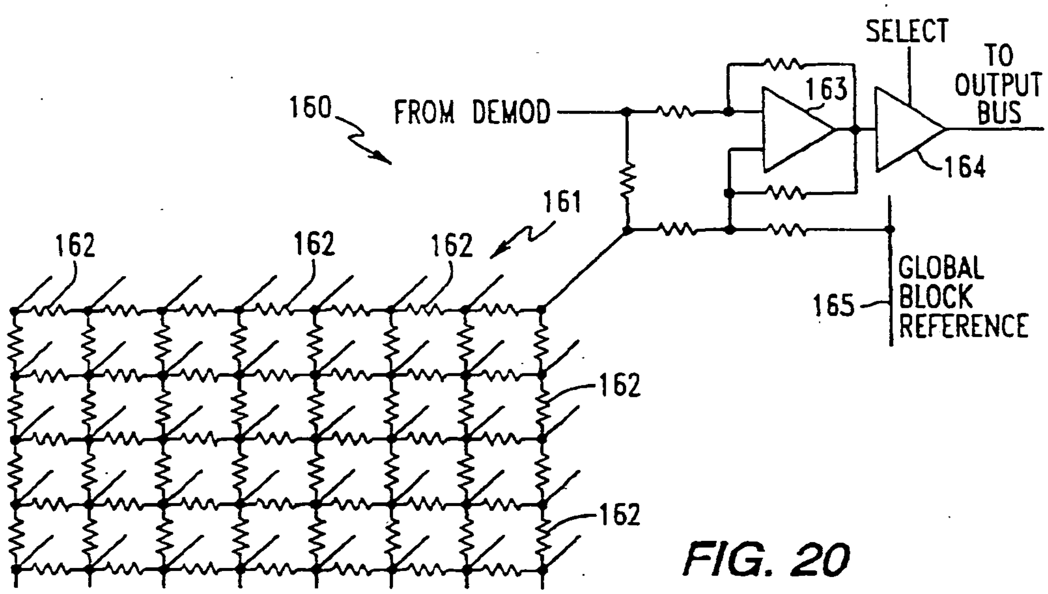

SELECT
TO OUTPUT BUS
160
FROM DEMOD
163
164
161
162
162
162
165
GLOBAL BLOCK REFERENCE
162
162

FIG. 20

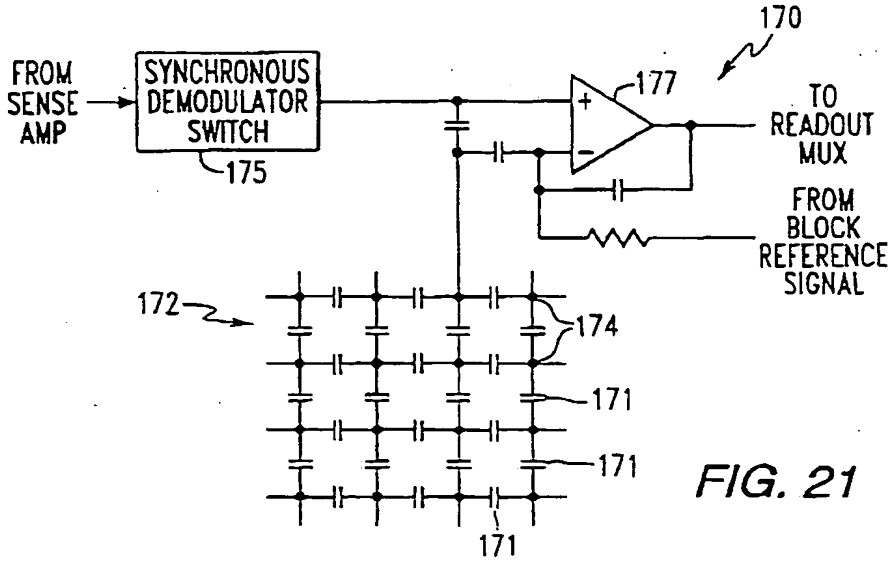


FIG. 21

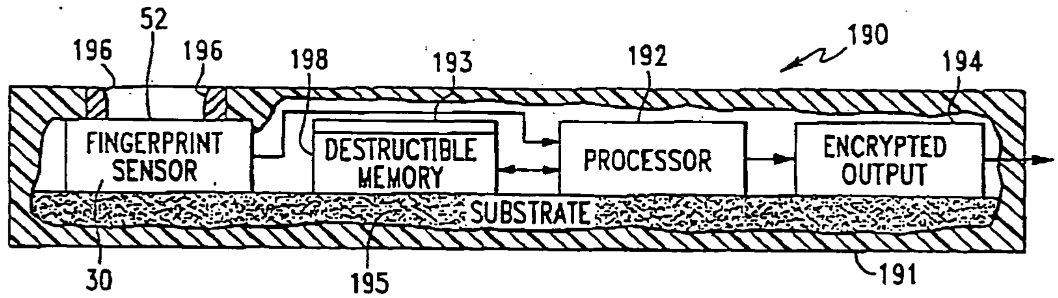


FIG. 22

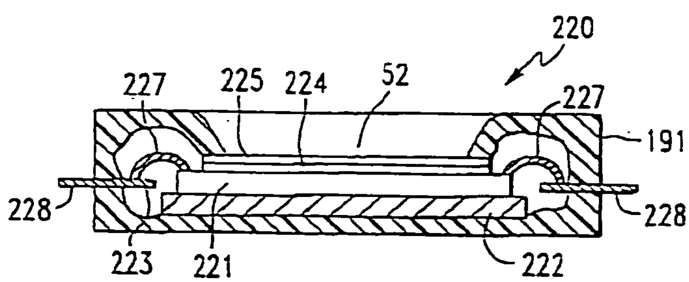


FIG. 23

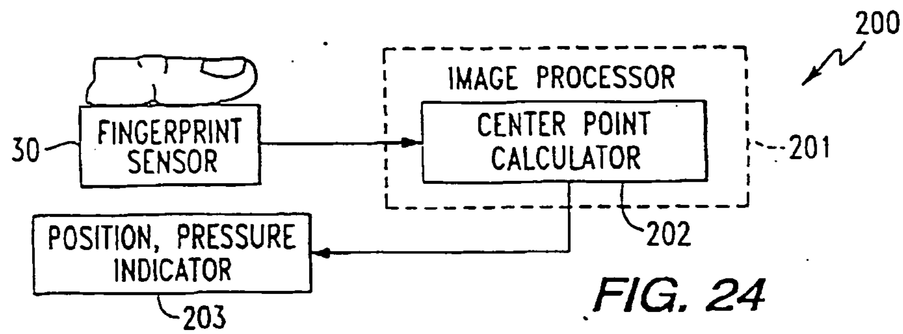


FIG. 24

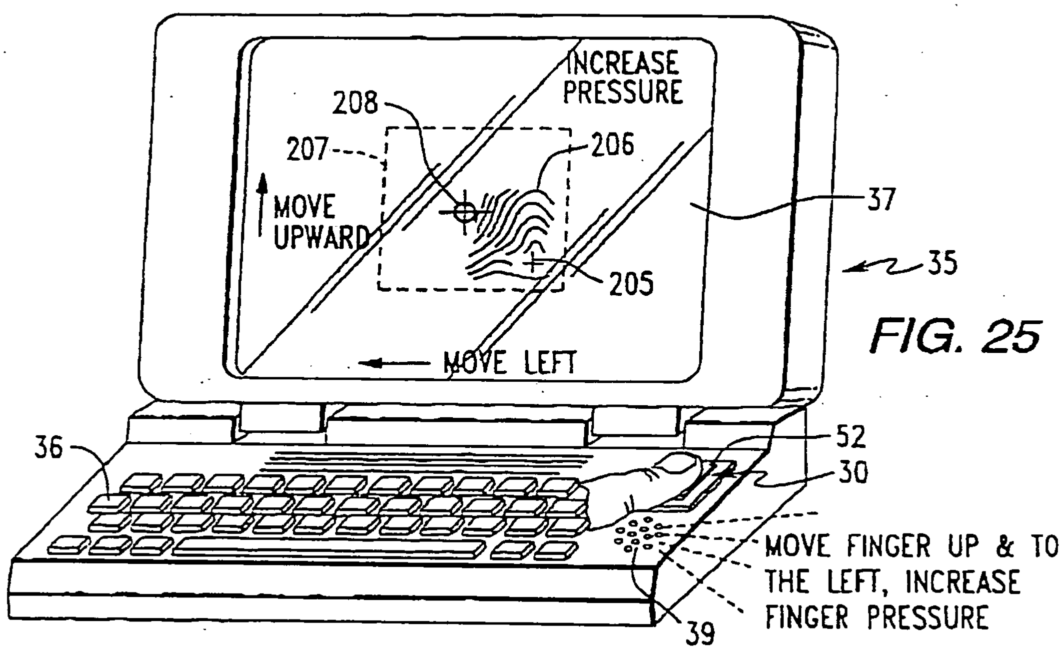


FIG. 25

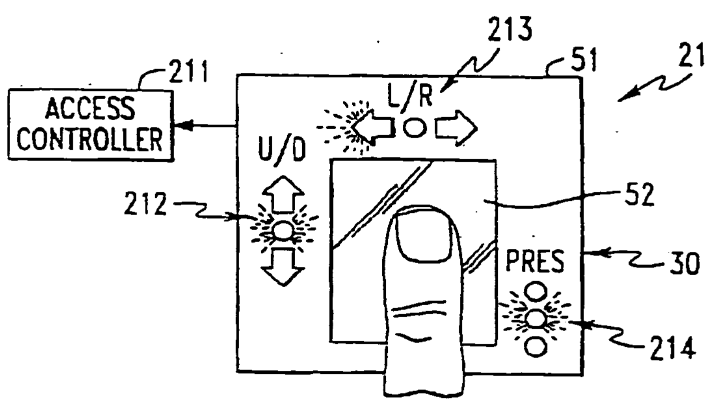


FIG. 26